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UNIT-5 :- VHF, UHF, and Microwave Antennas :-

OM SAI Sai Ram

Introduction to Reflector antennas :-

→ The reflector antennas are most important in microwave radiation applications. At microwave frequencies the physical size of the high gain antenna becomes so small to produce desired directivity.

→ In reflector antenna another antenna is required to excite it.

→ The antennas such as dipole, Horn, slot which feeds the reflector antenna.

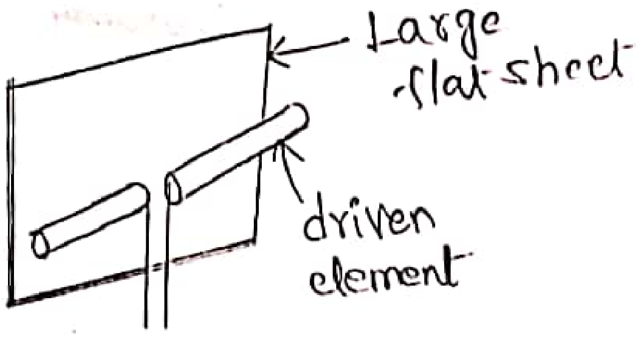
→ Dipole, Horn, slot antenna is called as "primary antenna", and reflector is called as "secondary antenna".

→ Reflector antenna canbe represented in any geographical configuration, but the most commonly used shapes are plane reflector, corner reflector and curved (or) parabolic reflectors.

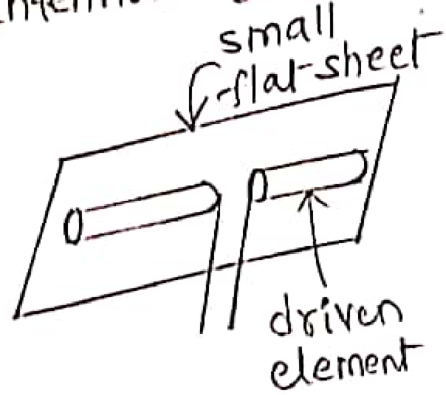
→ By using reflectors, the backward radiations from the antenna can be eliminated. Thus improving radiation pattern of an antenna.

→ Using reflectors, the radiation pattern of a radiating antenna can be modified

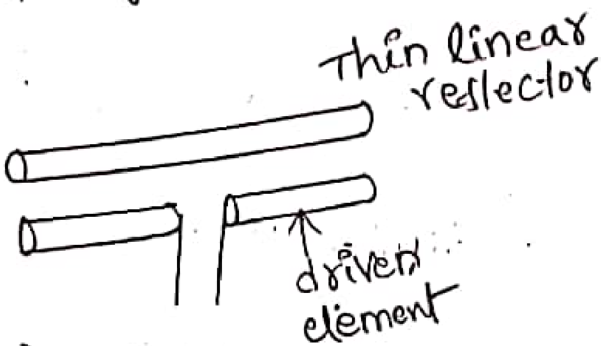
Different types of reflector antennas are



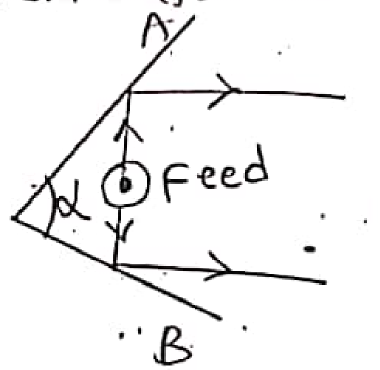
(a) Large flat sheet



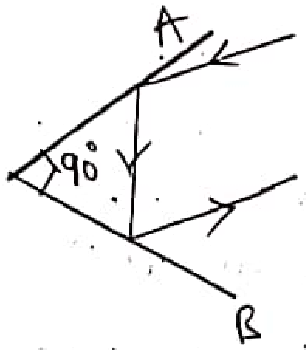
(b) small flat sheet



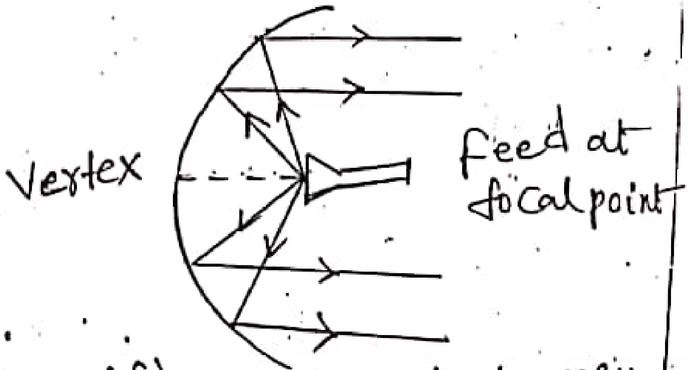
(c) Thin linear reflector antenna



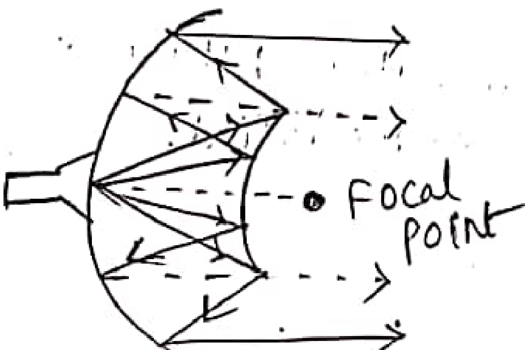
(d) Active corner reflector.



(e) passive corner reflector.



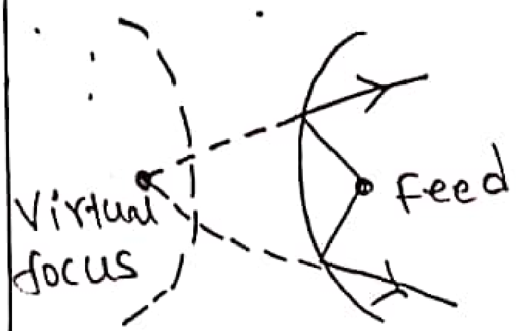
(f) curved reflector with front feed.



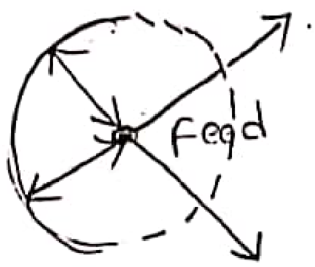
(g) curved (or) parabolic reflector with Cassegrain feed.

(h) elliptical reflector

ex



(i) hyperbolic reflector.

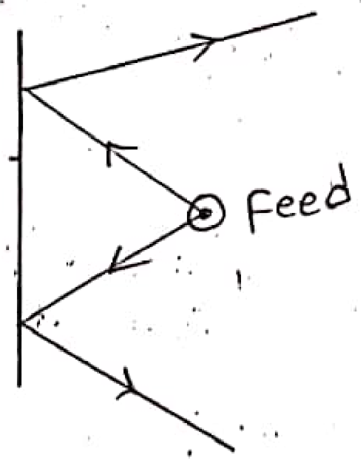


(j) circular reflector

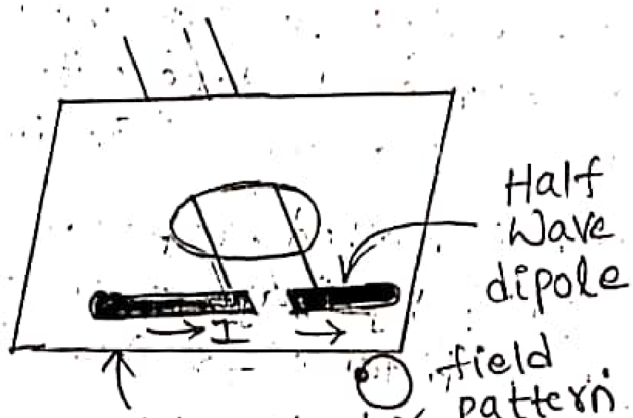
Flatsheet (or) plane reflectors :-

* The plane reflector is the simplest form of the reflector antenna. A flat sheet reflector can be considered to be made up of two flat sheets intersecting each other at an angle $\alpha = 180°$

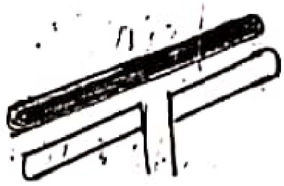
* When the plane reflector is placed infront of the feed, the energy is radiated in the desired directions.



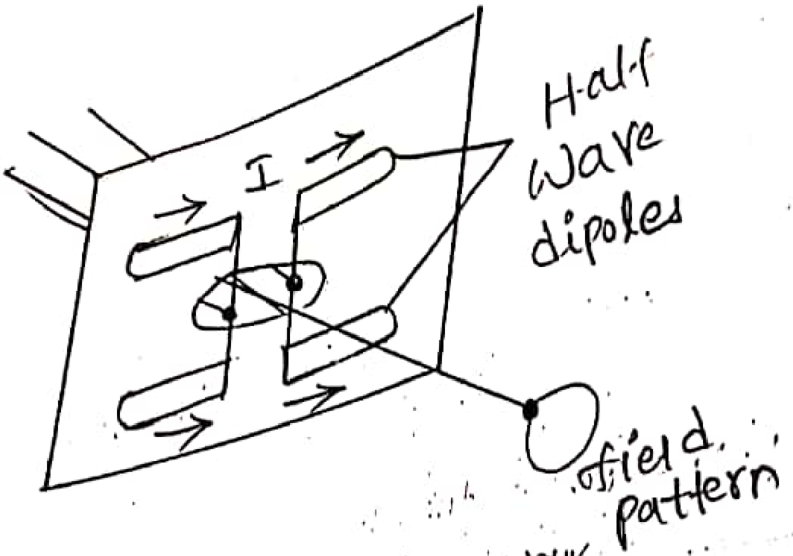
(a) plane reflector.



Examples :- Half wave dipole with plane reflector.



half wave dipole with reflector element

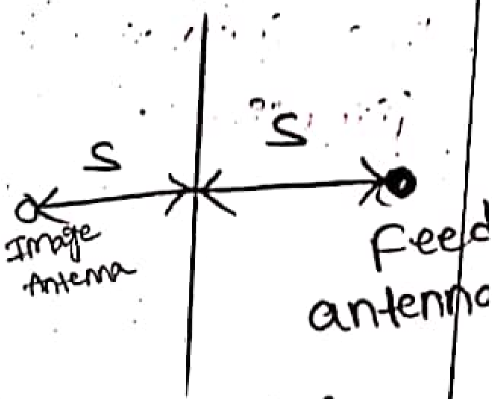


Half wave dipole array with plane reflector.

* The polarization of the radiating source and its position with respect to the reflector both are important as one can control radiating pattern, directivity, Impedance.

* The analysis of flat sheet reflector can be done with the help of method of images.

* In this method, reflector can be replaced by Image of an antenna at a distance 2S from feed antenna.



Antenna & its image at a distance 'S'.

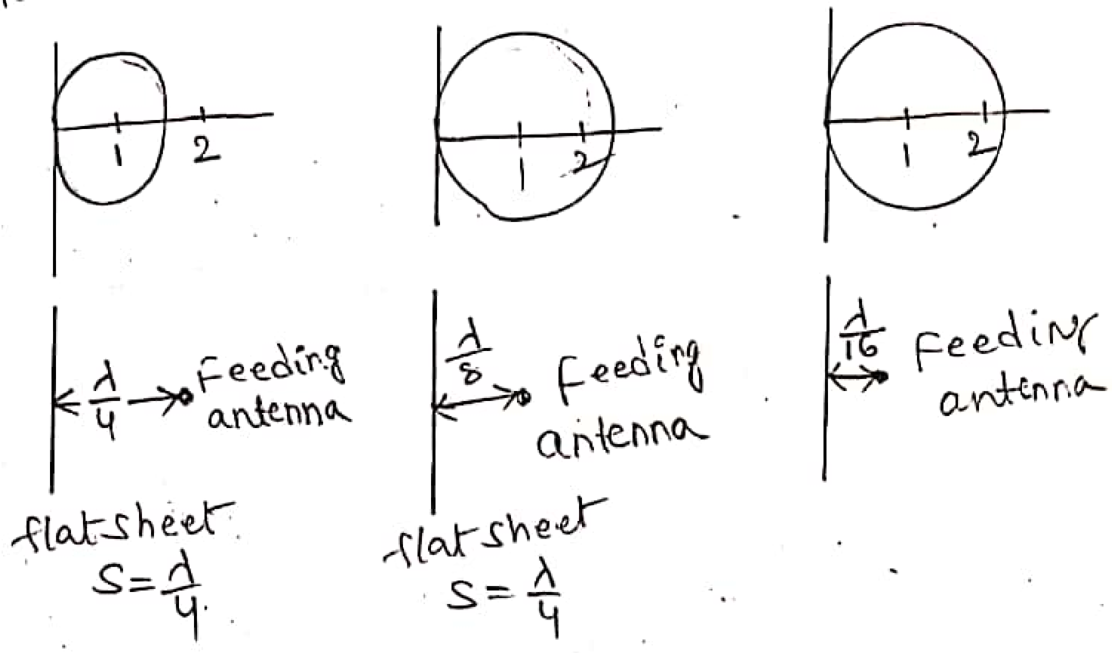
For an infinite plane reflector, assuming zero reflector losses, the gain of a $\frac{\lambda}{2}$ dipole antenna at a distance 's' is given by

$$G_f(\phi) = 2\sqrt{\frac{R_{11}+R_{LOSS}}{R_{11}+R_{LOSS}-R_{12}}}\left|\sin(S_r\cos\phi)\right|$$

and $S_r = \left(\frac{2\pi}{\lambda}\right)S.$ $\left(\because S_r = \text{radial distance},\ S = \text{distance}.\right)$

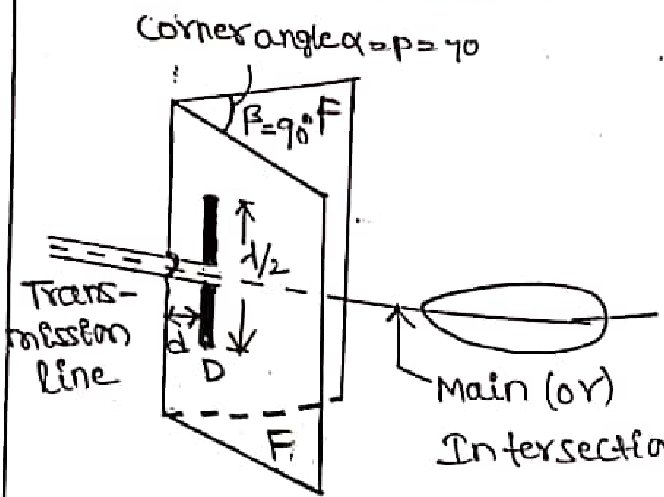
The gain of reflector relative to half wave dipole antenna is a function of the spacing between flat sheet and half wave dipole antenna. (3)

* When the spacing between half wave dipole and infinite sheet decreases, the gain will be increases.



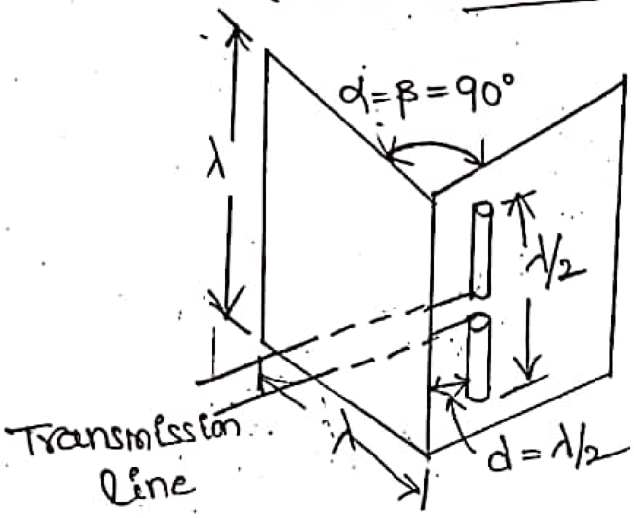
Corner Reflector :-

* The corner reflector antenna can be considered to be made up of two flat sheets meet at angle $\alpha = 90°$.
* The flat reflecting sheets meeting ~~at~~ angle (or) corner form an effective directional antenna.
* The corner reflector antenna is a driven antenna associated with a reflector.
* Generally driven antenna is a Half wave dipole and reflector can be constructed of two flat sheets meet at a corner (or) angle to form corner reflector and
* This arrangement with corner reflector and driven antenna is known as "corner reflector antenna".

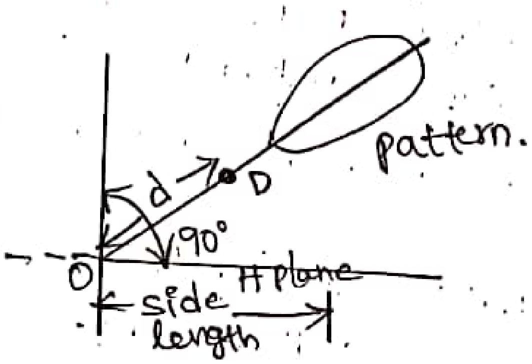


f = flat reflecting sheets
D = driven antenna

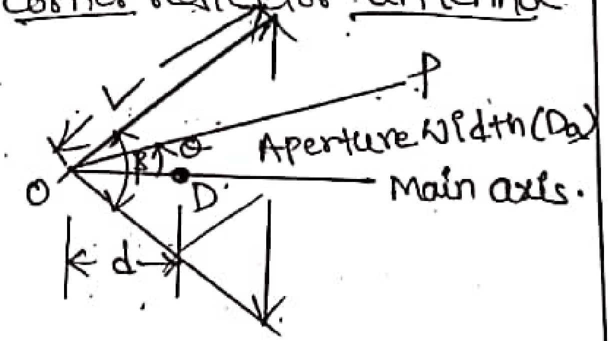
(a) Vertical corner reflector antenna.



(b) Horizontal corner reflector antenna

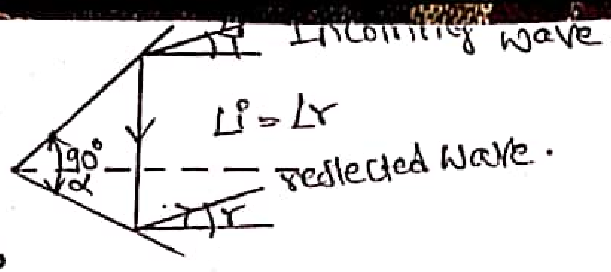


(c) Radiation pattern.



d = spacing between driven elements
α = β = corner angle
D = driven antenna.

(d) Active Corner reflector.



(e) passive corner reflector.

* If corner angle $\beta = \alpha = 90°$ then the two flat sheets meeting at a right angle forming a square corner reflector.
* When the corner reflector with the driven antenna is called "active corner reflector" for a wide range of corner $0 < \beta < \pi$
* When the corner reflector without the driven antenna is called "passive corner reflector" for a wide range of angle of incidence $0 < i < \pm\frac{\pi}{4}$
* The corner reflector antenna may be analysed by using the method of images for corner angle.

$$\boxed{\alpha = \beta = \frac{180°}{n}}$$ Where n = an integer = 1, 2, 3 . . .

Thus if $n = 1$, $\beta = 180°$ (or) π radian $\longrightarrow$ flat sheet reflector

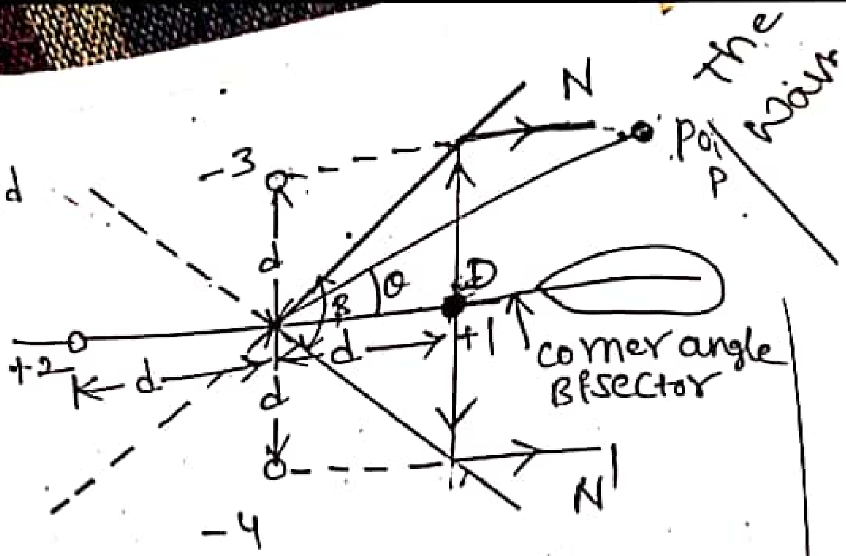
if $n = 2$, $\beta = 90°$ (or) $\frac{\pi}{2}$ radian $\longrightarrow$ square corner reflector.

if $n = 3$, $\beta = 60°$ (or) $\frac{\pi}{3}$ radian $\rightarrow$ corner reflector 60°

if $n = 4$ $\beta = 45°$ (or) $\frac{\pi}{4}$ radian $\rightarrow$ corner reflector 45°

$\therefore$ By method of images corner angles of $\pi, \frac{\pi}{2}, \frac{\pi}{3}, \frac{\pi}{4}$ can only be used.

* Let us consider method of images for square corner reflector
* The driven antenna is shown by 'D' and three images (+2, -3, -4) corresponding to driven antenna (+1).
* The driven antenna (half wave dipole) and its three images carry equal currents.



square corner reflector with driven element (+1) and three images (+2, -3, -4).

* driven antenna (+1) and image element (+2) are in same phase & -3 and -4 image elements are also in same phase.
* But there exists a 180° phase shift between phase of elements (+1, +2) and (-3, -4). The two negative images corresponds to single reflection of rays N and N', third +ve image (+2) corresponds to driven element (+1)

The field pattern $E_\phi(\theta)$ in the horizontal plane at a large distance r from the antenna is given by

$$E_\phi(\theta) = K' I_1 [\cos(\beta d \cos\theta) - \cos(\beta d \sin\theta)] \rightarrow (1)$$

Where K' = Constant,
I_1 = current in each element
$\beta = \frac{2\pi}{\lambda}$
d = distance between driven element & corner along bisector

Horn Antennas:-

* The horn antenna is most widely used simplest form of the microwave antenna. The horn antenna serves as a feed element for large radio astronomy, communication dishes and satellite tracking over the world.
* The horn antenna can be considered as a wave guide, which is flared out (or) opened out.
* When one end of the wave guide is feeded and other end is open, it radiates in open space in all directions.
* As compared with the two wire transmission line, the radiation through the waveguide is larger.

* In waveguide, the small amount of power is radiated in incident wave, while due to open circuit at other end large amount of power is reflected back.
* As one end of the waveguide is open circuited, the impedance matching with the free space is not perfect
* So at the edges of waveguide, diffraction occurs. that means interference of electromagnetic waves.
* Therefore To overcome these problems the mouth of the waveguide is flared (or) opened out in the shape of Horn.

Types of Horn Antennas:-

* A horn antenna is nothing but a flared out (or) opened out waveguide. The main function is to produce an uniform phase front with a aperture larger than waveguide to give higher directivity

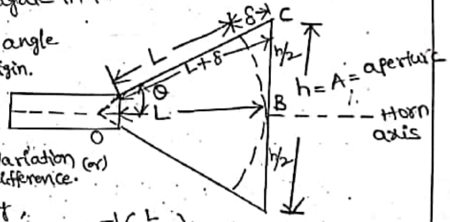
Horn Antennas.
- Rectangular Horn antennas
  - Sectorial Horn antennas
    - E-plane Sectorial Horn
    - H-plane Sectorial Horn.
  - Pyramidal Horn antennas
- Circular Horn antennas.
  - Conical Horn
  - Bi-Conical Horn.

Design characteristics of Horn antennas :-

Let us consider E-plane sectorial horn. The electromagnetic Horn produces uniform phase front with a larger aperture as compared to waveguide.

* consider an imaginary apex of horn. Assume that there exists a line source which radiates cylindrical waves.
* The constant (or) uniform wave fronts are cylindrical as the waves propagate in the direction radially outward.

θ = optimum aperture angle
A = aperture , O = origin.
L = axial length
2θ = flare angle.
δ = phase difference variation (or) path difference.



From the geometry,

$$\cos\theta = \frac{L}{L+\delta} \Rightarrow \theta = \cos^{-1}\left(\frac{L}{L+\delta}\right)$$

also $$\tan\theta = \frac{h/2}{L} = \frac{h}{2L} \Rightarrow \theta = \tan^{-1}\left(\frac{h}{2L}\right)$$

$$\therefore \boxed{\theta = \cos^{-1}\left(\frac{L}{L+\delta}\right) = \tan^{-1}\left(\frac{h}{2L}\right)} \rightarrow (1)$$

From right angle Triangle OBC

$$(L+\delta)^2 = L^2 + \left(\frac{h}{2}\right)^2 \quad (\because \text{pythagorous theorem})$$

$$\Rightarrow \cancel{L^2} + \delta^2 + 2L\delta = \cancel{L^2} + \frac{h^2}{4}$$

$$\therefore \delta^2 + 2L\delta = \frac{h^2}{4}$$

if 'δ' is small then δ^2 is Neglected.

$$\therefore 2L\delta = \frac{h^2}{4} \quad \text{where } \delta \ll L$$

$$\boxed{L = \frac{h^2}{8\delta}} \rightarrow (2)$$

Equations (1) (2) are called as Design equations.

When flare angle (2θ) is small, the aperture area for a specified Length 'L' becomes small. ∴ the directivity decreases.

* The directivity of maximum value can be obtained at the largest flare angle for which 'δ' does not exceed typical value such as
  - 0.25λ for E plane horn,
  - 0.32λ for conical horn,
  - 0.40λ for H-plane sectoral horn.
* The directivity of pyramidal and conical horn is highest as compared to other types of horns.

For E-plane horn phase difference up to 72° for δ<0.2λ
for H-plane horn phase difference upto 135° for δ<0.375λ

* In practical horn antennas flare angle varies from 40° to 15° which gives beam width = 66°, Directivity = 40, for L = 6λ,

for L = 50λ, beam width = 23° and Directivity = 120.

for optimum flare horn, the half power beam width is

$$\boxed{\theta_E = \frac{56^\circ\lambda}{a_E} \text{ (or) } \frac{56^\circ\lambda}{h}} \quad \boxed{\theta_H = \frac{67^\circ\lambda}{a_H} \text{ (or) } \frac{67^\circ\lambda}{w}}$$

The relation between directivity and aperture area is

$$\boxed{D = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \times E_{ap} \times A_p}{\lambda^2}}$$

But $\frac{A_e}{A_p} = E_{ap}$ = aperture efficiency.

A_e = effective aperture in m^2
A_p = physical aperture in m^2

Features of Horn antennas:-

* Horn antenna is used with waveguide and it is used as radiator.
* It is generally used with paraboloidal antenna as a primary antenna.
* For pyramidal horn, the directivity increases if the flare of the horn is in more than one direction.

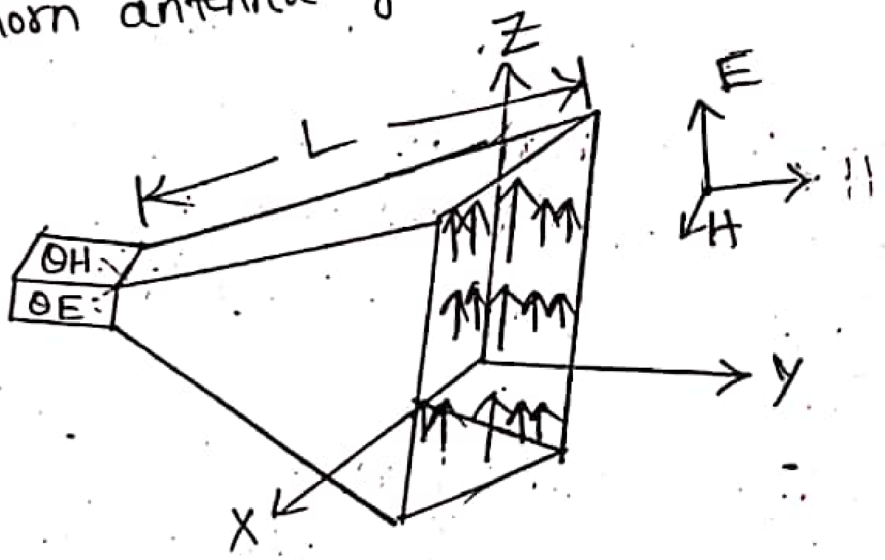
Applications of Horn antennas:-

* The horn antenna is used as feed element in antennas such as parabolic reflectors.
* It is the most wide used antenna for measurement of various antenna parameters.

pyramidal Horn :-

* pyramidal horn antenna is obtained, when the flaring is done along the both the walls of the rectangular waveguide in the direction of both the electric and magnetic field vectors.

* For pyramidal horn antenna gain is 12-25 dB.



circular Horn antennas :

- Consider the cross section of pyramidal horn as shown in figure.

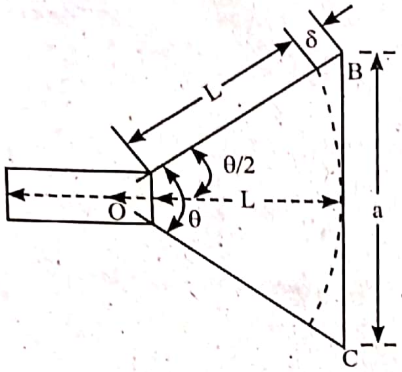


Figure: Pyramidal Horn Antenna

- Consider an imaginary apex of horn. Let a line source radiate cylindrical waves. These uniform wave fronts are cylindrical as the waves propagate in the direction radially outwards.
- The phase varies at different points on the aperture from the origin since the path length of wave is different from different distances from apex to the aperture. Assume δ as the path difference,

From the geometry of figure, we have,

$$\cos\frac{\theta}{2} = \frac{L}{L+\delta} \quad \text{... (1)}$$

and $$\tan\frac{\theta}{2} = \frac{a/2}{L} \quad \text{... (2)}$$

Hence, $$\theta = 2\cos^{-1}\left(\frac{L}{L+\delta}\right)2\tan^{-1}\left(\frac{a}{2L}\right) \quad \text{... (3)}$$

Here,

δ – Path length difference

θ – Flare angle

a – Aperture (a_E for E-plane and a_H for H-plane)

L – Length of a horn or optimum length

- From right angle triangle OBC

$$(L + d)^2 = L^2 + \left(\frac{a}{2}\right)^2 \text{ or } L^2 + \delta^2 + 2L\delta = L^2 + \frac{a_e^2}{4}$$

For very small value of δ, δ^2 is insignificant

$$\Rightarrow 2L\delta = \frac{a^2}{4} \text{ or } L = \frac{a^2}{8\delta} \; (\delta << L) \quad \text{... (4)}$$

- Equations (3) and (4) are called design equations of the horn antenna.

Optimum Horn

- For a uniform phase front, a long horn with a small flare angle is necessary. But in practice short horn is feasible.
- An optimum horn is a compromise between the two in which d is chosen to be small fraction of wavelength λ so that field is distributed uniformly over the entire aperture.

Characteristics

1.
- If L is kept constant and the values of a and θ are increased, then, the directivity of horn increases.
- Further, the value δ approaches to 180° resulting in the phase reversal of the field at the edges of horn with respect to the field present at its axis.
- When the value of δ reaches exactly 180°, then the directivity decreases with increase in the beam width.

2. Further increase in the value of θ approximates equation (1) to unity.

i.e., $$\frac{L}{L+\delta} \approx 1$$

Where, δ is ignored.

3. At the maximum value of θ, maximum directivity occurs where the value of δ is limited to a value of δ_0.

For optimum horn, equation (1) is rewritten as,

$$\cos\theta/2 = \frac{L}{L+\delta_0}$$

$$\Rightarrow \text{Optimum } \delta = \delta_0 = \frac{L}{\cos\theta/2} - L \quad \text{... (5)}$$

$$\Rightarrow \text{Optimum Length} = L = \frac{\delta_0\cos\theta/2}{1-\cos\theta/2} \quad \text{... (6)}$$

- It is to be noted that the value of δ_0 should lie between 0.1λ to 0.4λ (λ is wavelength of free space).

Equations (5) and (6) are the optimum dimensions of horn.

- For optimum flare horn, half power beamwidth is

$$\text{HPBW}_{(\text{H-plane})} = \frac{67°\lambda}{a_H}$$

$$\text{HPBW}_{(\text{E-plane})} = \frac{56°\lambda}{a_E}$$

- For a rectangular horn,

$$A_P = a_E a_H$$

$$a_H = 2L\tan\frac{\theta_H}{2}$$

$$a_E = 2L\tan\frac{\theta_E}{2}$$

Where,

a_E – E-plane

a_H – E-plane

A_e – Effective aperature (m²)

A_p – Physical aperature (m²)

ε_{ap} – Aperature efficiency $(A_e/A_p) = \frac{4\pi\varepsilon_{ap}A_p}{\lambda^2}$

Directivity, $$D = \frac{4\pi A_e}{\lambda^2}$$

- For a conical horn,

  $A_P = \pi r^2$

  Where,

  r – Radius of aperture

  θ_E – Flare angle in H-plane

  θ_E – Flare angle in E-plane

- Typically, it is assumed that a_E, a_H or r are at least 1λ with aperture efficiency $\varepsilon_{ap} \simeq 0.6$, then, directivity is given by,

$$D \simeq \frac{7.5A_p}{\lambda^2}$$

- For a pyramidal rectangular horn,

$$D \sim 10 \log(7.5a_{E\lambda}\, a_{H\lambda})$$

Q62. Design a simple pyramidal horn to work in 10.0 GHz range.

Ans:

Given that

in a travelling wave called leaky wave.

Q3. What are the different mechanisms of propagation of electromagnetic waves? Explain.

Model Paper-1, Q9(a)

(or)

In which frequency range ground wave propagation is effective. Why? Nov.-15, Set-3, Q1(e) M[4]

(Refer Topic: Ground Wave or Surface Wave Propagation)

Ans:

Modes of Propagation

Electromagnetic waves may travel from transmitting antenna to the receiving antenna in a number of ways.

Different propagations of electromagnetic waves are as follows,

1. Ground wave propagation
2. Sky wave propagation
3. Space wave propagation
4. Tropospheric scatter propagation.

This classification is based upon the frequency range, distance and several other factors.

1. Ground Wave Propagation

- Ground wave propagation is also known as surface wave propagation. This propagation is practically important at frequencies up to 2 MHz.
- Ground wave propagation exists when transmitting and receiving antenna are very close to the earth's curvature.
- Ground wave propagation suffers attenuation while propagating along the surface of the earth. This propagation can be subdivided into two types which are space wave and surface wave propagation.

Applications

- Ground wave propagation is generally used in TV, radio broadcasting etc.

2. **Sky Wave Propagation**

- Sky wave propagation is practically important at frequencies between 2 MHz to 30 MHz. Here the electromagnetic waves reach the receiving point after reflection from an atmospheric layer known as ionosphere. Hence, sky wave propagation is also known as 'ionospheric wave propagation'.
- It can provide communication over long distances. Hence, it is also known as point-to-point propagation or point-to-point communication.

Disadvantage

- Sky wave propagation suffers from fading due to reflections from earth surface, fading can be reduced with the help of diversity reception.

Applications

- It can provide communication over long distances.
- Global communication is possible.

3. **Space Wave Propagation**

- Space wave propagation is practically important at frequencies above 30 MHz.
- It is also known as tropospheric wave propagation because the waves reach the receiving point after reflections from tropospheric region.
- Troposphere region in atmosphere within16 km above the surface of earch.
- In space wave propagation, signal at the receiving point is a combination of direct and indirect rays. It provides communication over long distances with VHF, UHF and microwave frequencies. Space wave propagation is also known as "line of sight propagation".
- The field strength of receiver depends on:
  - → Direct ray from transmitter
  - → Ground reflected ray
  - → Reflected and refracted rays from the atmosphere
  - → Diffracted rays around the curvature of earth and so on.

Applications

- Space wave propagation is used in satellite communication.
- It controls radio traffic between a ground station and a satellite.

4. **Troposcatter Propagation**

- Troposcatter propagation is also known as forward scatter propagation, it is practically important at frequencies above 300 MHz.
- This propagation covers long distances in the range of 160 to 1600 km.